SHOCK

A DISCUSSION OF PYROTECHNIC SHOCK CRITERIA

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This paper presents and discusses a set of criteria for predicting pyrotechnic shock environments. The spectra to be expected near the source are presented for a variety of pyrotechnic devices, along with a set of attenuation curves for various types of aerospace structures.

INTRODUCTION

In recent years, pyrotechnic devices have been used extensively in the aerospace industry. These devices include linear shaped charges, explosive bolts, separation nuts and bolts, and cartridge-actuated devices such as pin-pullers and bolt cutters. The environments producted by these pyrotechnics can cause damage and/or failure to equipment and structure. As a result, the technology to evaluate these environments is currently being developed.

Today the state-of-the-art of this technology is limited mainly to testing techniques, both to predict the environment and to qualify equipment to the predicted environment. Current testing techniques utilize a variety of simple and complex shock pulse generators and simulated or prototype hardware. The literature depicts many testing methods; and, once an environment has been established, a reasonable test can be produced. The method of predicting the shock environment makes use of available test data to empirically establish the environment.

A recently completed NASA contract with Goddard Space Flight Center involved the compilation and analysis of pyrotechnic shock data collected from the aerospace industry. The data are in the form of acceleration time histories and their related shock spectra for a wide variety of pyrotechnic devices and aerospace structures. A summary of the total program was presented in a paper by W. P. Radar and W. F. Bangs entitled "A Summary of Pyrotechnic Shock in the Aerospace Industry" during the 41st Shock and Vibration Symposium. One aspect of this contract involved using the data to develop criteria for predicting pyrotechnic shock environments. The criteria are presented as a set of source shock spectra for a variety of pyrotechnic devices and as a set of attenuation curves for various types of aerospace structures.

This paper presents and discusses these criteria. The types of pyrotechnic devices commonly used and the spectra to be expected near the source for each device are described. The order of severity of the various devices is presented and a set of attenuation curves is given for a variety of aerospace structures. And finally, an attenuation curve for a constant velocity line is presented and discussed.

DATA SOURCE

The principal purpose of Contract NAS5-15208 with Goddard Space Flight Center was to compile and analyze pyrotechnic shock data from the aerospace industry to provide a single reference for shock data and to develop an understanding of the parameters involved. A total of 2837 measurements were compiled, reduced, and presented in four data volumes [1]. A separate volume describes the work accomplished and summarizes the analyses. A sixth volume contains guidelines defining the design information applicable to structure and equipment subjected to a pyrotechnic shock environment.

The guidelines include empirical curves obtained from the data for various types of explosive devices and for a variety of aerospace structures. The empirical curves are not to be considered a statistical estimate but do suggest a representative sample from a limited number of tests. The guidelines can be used most effectively in conjunction with the remaining five volumes of Ref. [1], where each individual test is described and the test data are presented.

SHOCK SPECTRUM CHARACTERISTICS

In a normal pyrotechnic shock test program, the time histories of acceleration at a number of locations are measured and recorded. Because the signature of the time history is quite complex due to the nature of the shock and the intervening structure, the frequency content is not immediately obvious. Therefore, spectral analyses are performed to obtain the frequency information. An acceleration shock spectrum is a plot of the maximum response acceleration of a single-degree-of-freedom oscillator versus the resonant frequency of the oscillator, where base excitation of the oscillator is assumed. A shock spectrum displays both amplitude and frequency information characteristic of the time history, a concept used extensively in the aerospace industry to specify shock environments.

Near the explosive source the acceleration shock spectrum is characterized by a high-amplitude curve that peaks in the high-frequency range, usually well above 1000 Hz. In the low-frequency range, a shock spectrum shows a definite tendency of a constant velocity line, which on a logarithmic plot of the acceleration shock spectrum has a numerical slope of one.

As the shock pulse propagates through the structure, the acceleration amplitude is attenuated. This attenuation is directly proportional to the distance from the source as measured along the shock path. However, the amplitude attenuation is a function of frequency, and the high-frequency range attenuates more rapidly than the low. An example of this characteristic can be seen in Fig. 1, which shows two spectra, one measured near the shock source and the second more than 100 in. from the source. The high-frequency amplitude can attenuate from one to two orders of magnitude in 100 in., while the low-frequency amplitude usually attenuates less than an order of magnitude.

The effect of different attenuation rates can be accounted for by determining two parameters: the attenuation rates of the peak acceleration and of a constant velocity line in the low-frequency range. However, the constant velocity line can be difficult to estimate from a spectrum because of resonant acceleration peaks due to the response of the local structure.

SPECTRUM DETERMINATION

A shock spectrum is used primarily for specifying equipment qualification levels. These levels can be obtained from a full-scale test of the actual structure, but a full-scale test is not always possible. A preliminary estimate of a spectrum can be obtained from the expected level of the explosive device at the source by using empirical attenuation curves. The information for estimating the spectrum level is given in the following sections. These guidelines are strictly empirical and are not intended to represent all applications. Best results can be obtained by using these curves and referring to the data in Ref. [1].

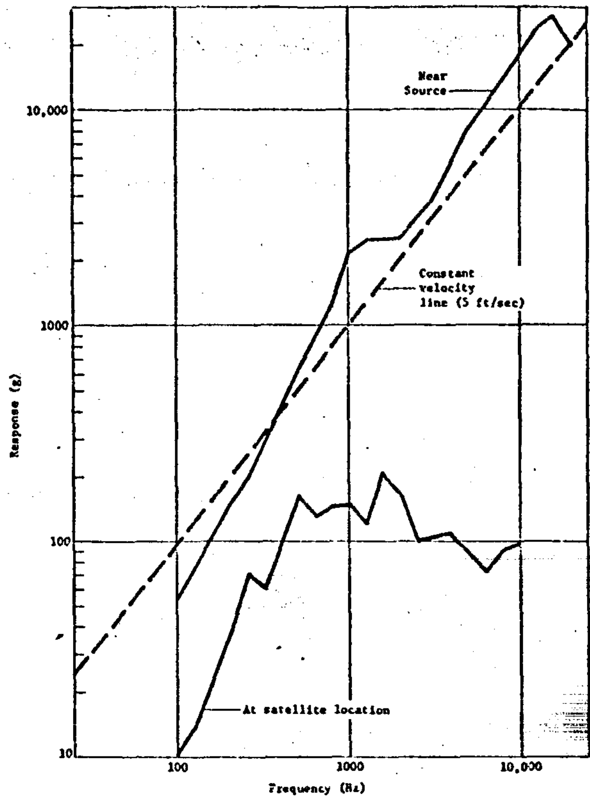

Fig. 1 - Shock spectra at source and satellite location

SOURCE SPECTRA

The following pyrotechnic devices are used in the aerospace industry to affect flight events. The devices are listed in their estimated order of severity.

1. Linear charges (mild detonating fuse and flexible linear shaped charge);
2. Separation nuts and explosive bolts;
3. Pin-pullers and pin pushers;
4. Bolt-cutters, pin-cutters, and cable-cutters.

Absolute acceleration shock spectra for these four devices are discussed below and presented in Figs. 2 through 5. The suggested environments are based on data measured within 10 in. of the explosive source, and the shock spectrum analyses are presented for a damping factor of 5%, i.e., an amplification factor (Q) of 10. These curves represent an envelope of a few measurements and cannot be considered a statistical estimate.

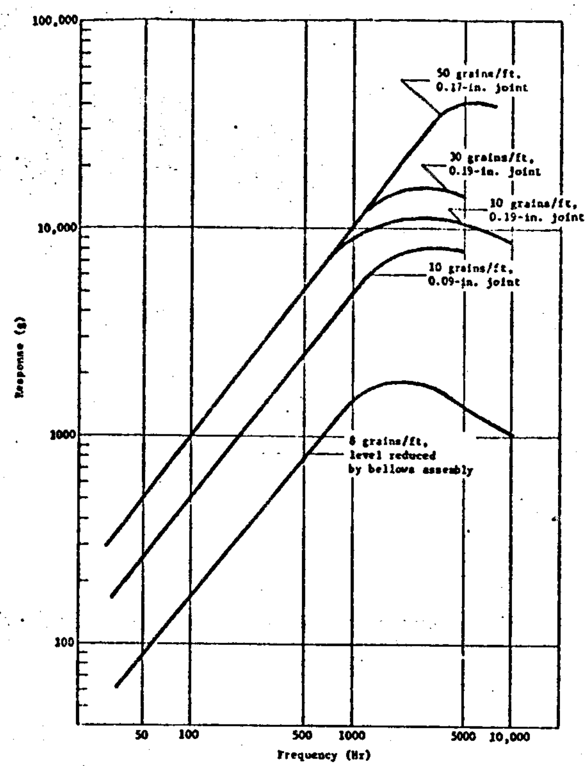

Fig. 2 - Suggested environment produced by linear pyrotechnic devices

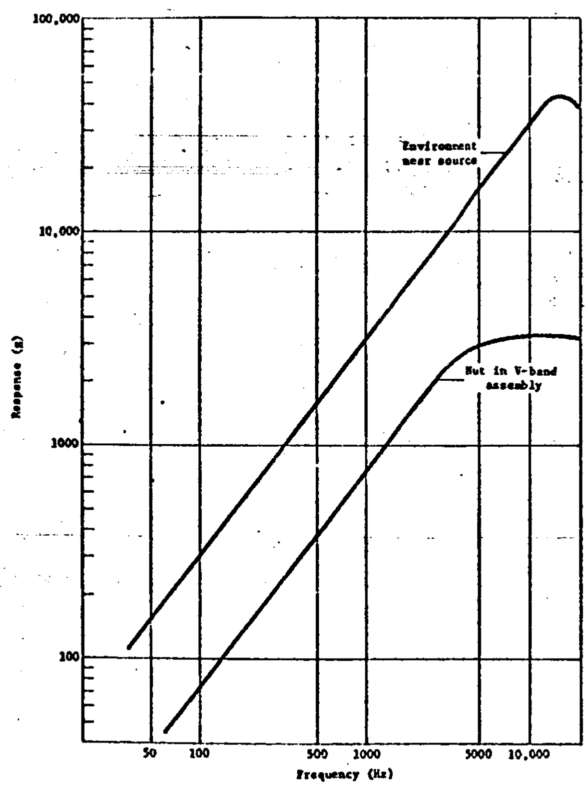

Fig. 3 - Suggested environment produced by separation nuts and explosive bolts

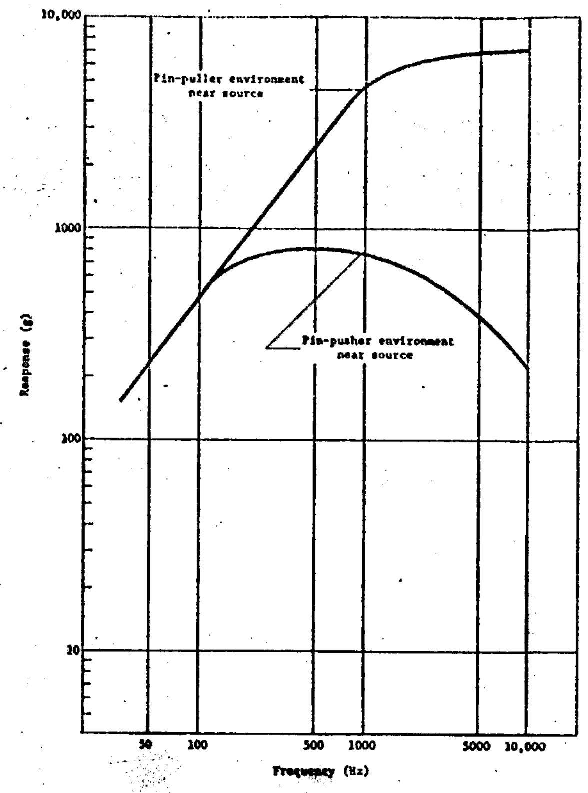

Fig. 4 - Suggested environments produced by pin-pullers and pin-pushers

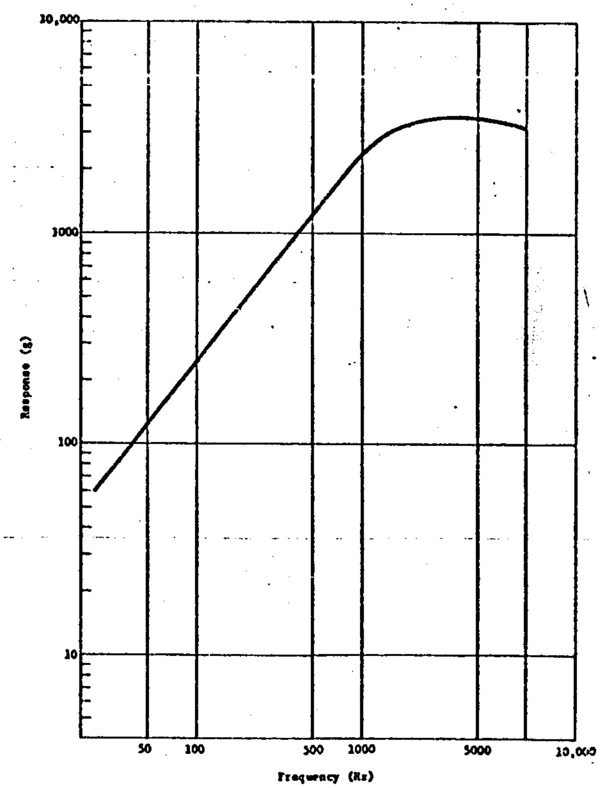

Fig. 5 - Suggested environment produced by bolt-, pin-, and cable-cutters

Linear Explosives

Linear explosive pyrotechnic devices are usually used in separation joints. The level of the environment produced by such a joint separation depends on the thickness of the material cut and the size of the explosive charge. The level of the spectrum increases with an increase of either of these parameters. Figure 2 presents the suggested environment produced by separation joints for several combinations of joint thickness and charge size. Also included is the environment for a bellows assembly, a separation device designed to lower the shock level.

The acceleration time histories characteristic of linear explosive devices have an effective duration of approximately 3 msec.

Separation Nuts and Explosive Bolts

Figure 3 presents the suggested shock environments produced by the detonation of a separation nut or explosive bolt. Two levels are shown: one for the device alone and one for a V-band assembly employing separation nuts or explosive bolts.

The acceleration time histories near the shock source characteristically decay in about 3 msec due to the presence of high-frequencies.

Pin-Pullers and Pin Pushers

Figure 4 presents the suggested shock environments produced by the detonation of pin-pulling and pin pushing pyrotechnic devices.

The acceleration-time histories characteristic of pin-pullers have an effective duration of 5 to 15 msec, while the pin-pusher is a softer, lower-frequency device that may have an effective duration of up to 50 msec.

Bolt-, Pin-, and Cable-Cutters

Figure 5 presents the suggested environments produced by the detonation of bolt-, pin-, and cable-cutting devices.

ATTENUATION CURVES

This section contains attenuation curves for the various types of structures listed in Table 1. These curves relate the predicted attenuation of the peak acceleration level of a shock spectrum to the distance from the shock source. These curves are normalized to a factor of one at the source and are to be used with the spectra curves given for the shock sources above. The normalization measurements are assumed to be 5 in. from the source.

TABLE 1
List of Structures for Attenuation Curves

Structure	Description	Fig. No.
Cylindrical shell	Without stringers or ring/frame	6
Skin/ring frame	Longeron or stringer of skin/ring frame	7
Ring/frame	Circumferential ring frame of skin/ring frame with longeron	8
Primary truss	Truss members, including the effects of joints	9
Complex airframe	Airframe structure, including skin and truss structure	10
Complex equipment	Equipment mounting, such as a payload truss network	11
Honeycomb	Honeycomb used as load-carrying structure	12

Because these curves are generated from limited data for each type of structure, they are to be used with discretion; since structures vary so greatly, the levels predicted by these curves can be in error. Consequently, we recommend that the shock levels be confirmed by a full-scale verification test on the flight-configured hardware.

CONSTANT VELOCITY ATTENUATION

As shown in Fig. 1, low-frequency accelerations attenuate with distance less rapidly than those at high frequencies. One way to account for this effect is to specify the attenuation of a constant velocity line with distance. A shock spectrum for a location removed from the source can then be predicted by specifying the two attenuated parameters -- the acceleration peak and a constant velocity line.

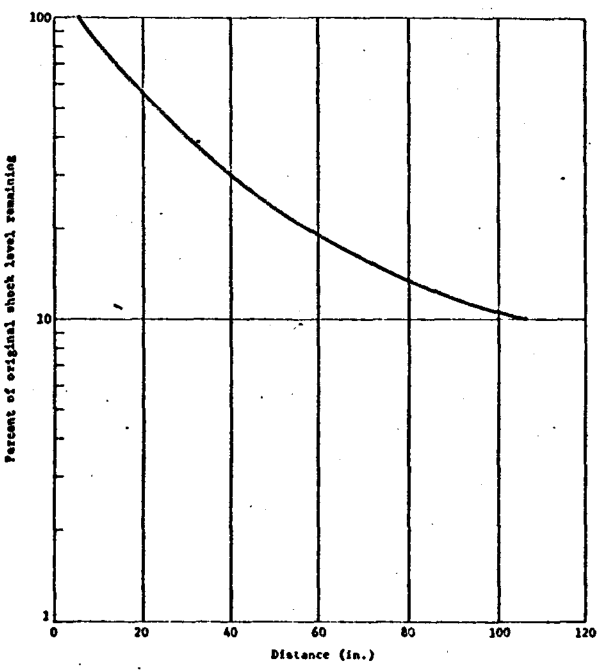

Fig. 6 - Attenuation for cylindrical shell

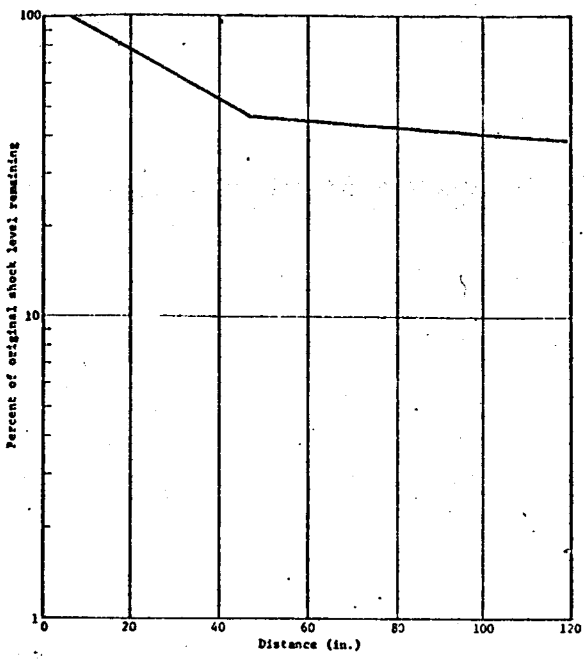

Fig. 7 - Attenuation for longeron or stringer

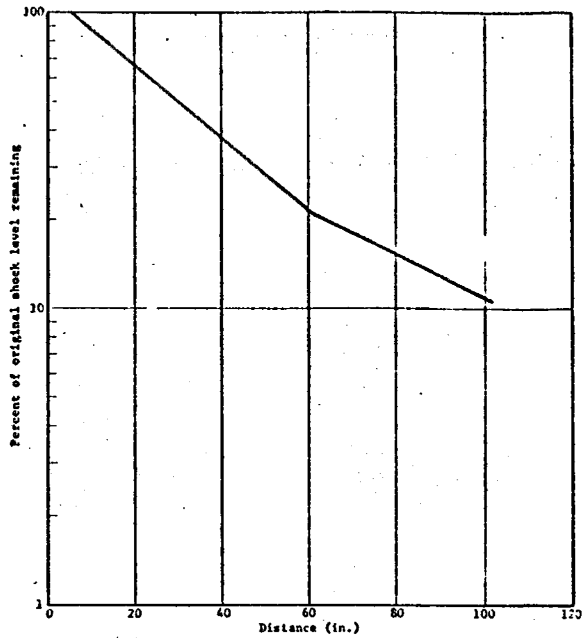

Fig. 9 - Attenuation for primary truss

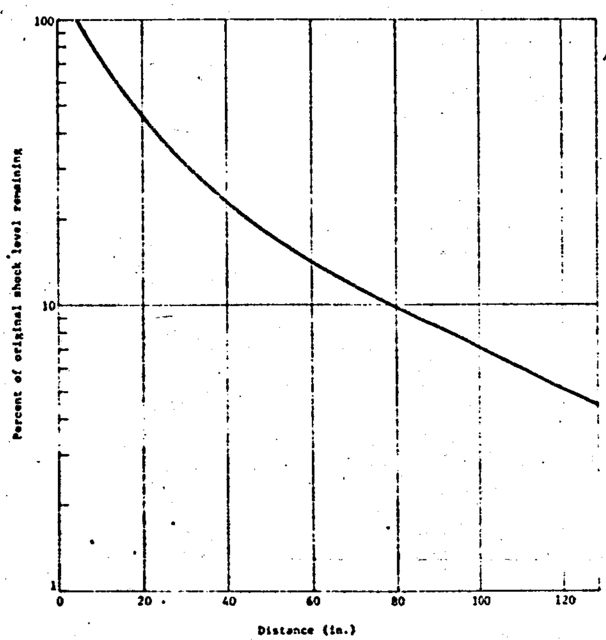

Fig. 8 - Attenuation for ring frame

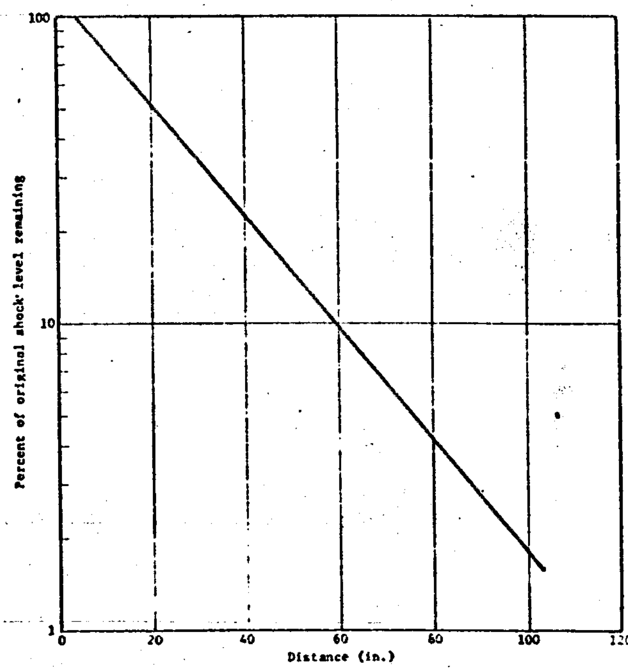

Fig. 10 - Attenuation for complex airframe

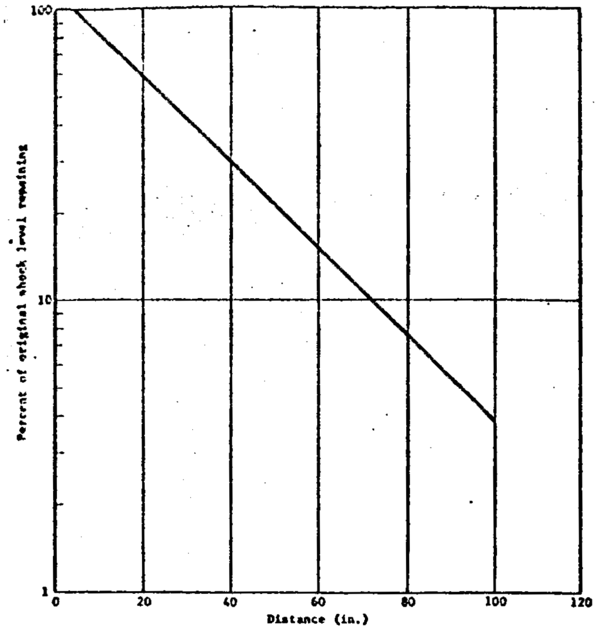

Fig. 11 - Attenuation for equipment mounting structure

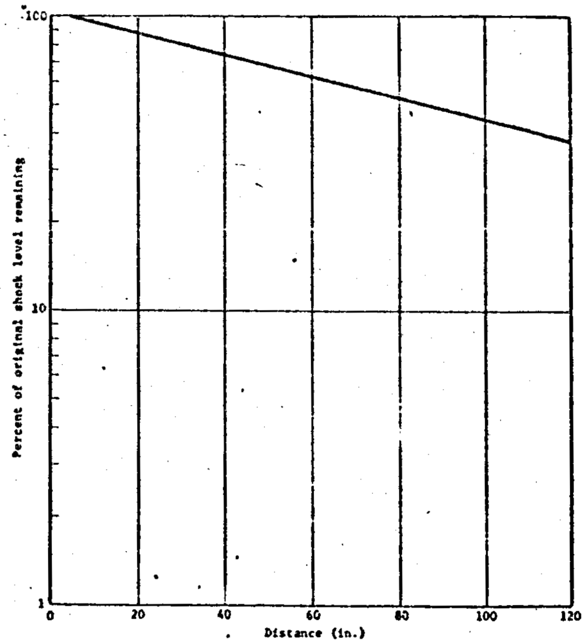

Fig. 12 - Attenuation for honeycomb

Volume one of Ref. [1] discusses the constant velocity concept and presents attenuation curves for this parameter taken from data on a truss structure. A composite of these curves is presented in Fig. 13, where the attenuation curve is normalized to a factor of one. Notice that the curve becomes flat, reflecting the fact that the constant velocity reduces to a certain level and stops. The constant velocity line is sometimes difficult to observe on spectra for locations far removed from the source since resonant peaks will appear in the low-frequency range of the spectrum, as in Fig. 1. It must be emphasized that this curve is obtained from limited data and also that the concept of a constant velocity line is not well established. Two recent articles discuss this concept in detail [2, 3] and relate it to damage potential. The curve in Fig. 13 is presented to account for the difference in attenuation rates over the frequency range of the spectra. Hopefully, the concept of constant velocity as applied to the shock spectra of complex time histories will be studied in more detail in the future.

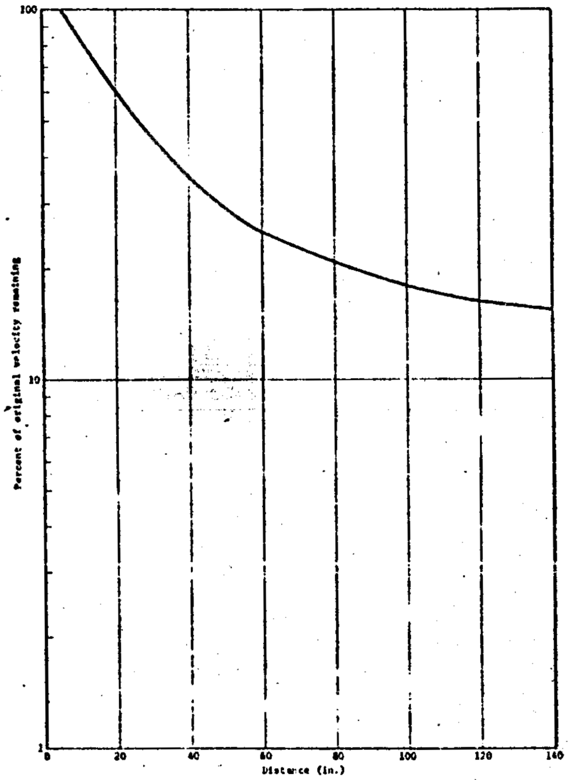

Fig. 13 - Attenuation for constant velocity line

DISCUSSION

The results presented in this paper represent an attempt to provide design criteria for pyrotechnic shock. The results are empirical and, due to the large variations among structural configurations, do not provide all the answers. The curves must be used with caution.

The subject of constant velocity lines is currently being studied in the industry, and there is strong evidence of its relationship to damage potential. In this paper the attenuation of this line is used to account for the variation in acceleration with frequency. The data used to predict this attenuation curve are limited, and the entire subject of a constant velocity line needs a great deal of attention.

ACKNOWLEDGEMENTS

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2. W. H. Roberts, "Explosive Shock," Shock and Vibration Bulletin, No. 40, Part 2, Dec. 1969.

3. H. A. Gaberson and R. H. Chalmers, "Modal Velocity as a Criterion of Shock Severity," Shock and Vibration Bulletin, No. 40, Part 2, Dec. 1969.

DISCUSSION

Mr. Schell (Shock Vibration Information Center): I am puzzled on the modifications to the original spectrum. You reduced both the peak acceleration and the velocity according to criteria determined from the data. I thought that I saw also, in some of the graphs, an attenuation of the high frequency content that differed from plain peak reduction. In other words, you were taking into account the fact that the high frequencies attenuate more rapidly than the low frequencies, is that right?

Mr. McGrath: This is what we are trying to account for. It is a very complex phenomenon. The high frequencies attenuate at different rates throughout the range. We are trying to account for this by a simple and empirical method. Let me also emphasize that the information we presented was envelopes taken from quite a bit of data. We take data, envelope it with one curve, and then use that curve as the attenuation curve. So we are trying to account for a rather complex situation with two simple parameters.